

Progress on rare K and π decays from BNL E949

- $K^+ \rightarrow \pi^+ \bar{v}v$ with $p_\pi < 195 \text{ Mev/c}$ (PNN2)
- $\pi^0 \rightarrow v\bar{v}$

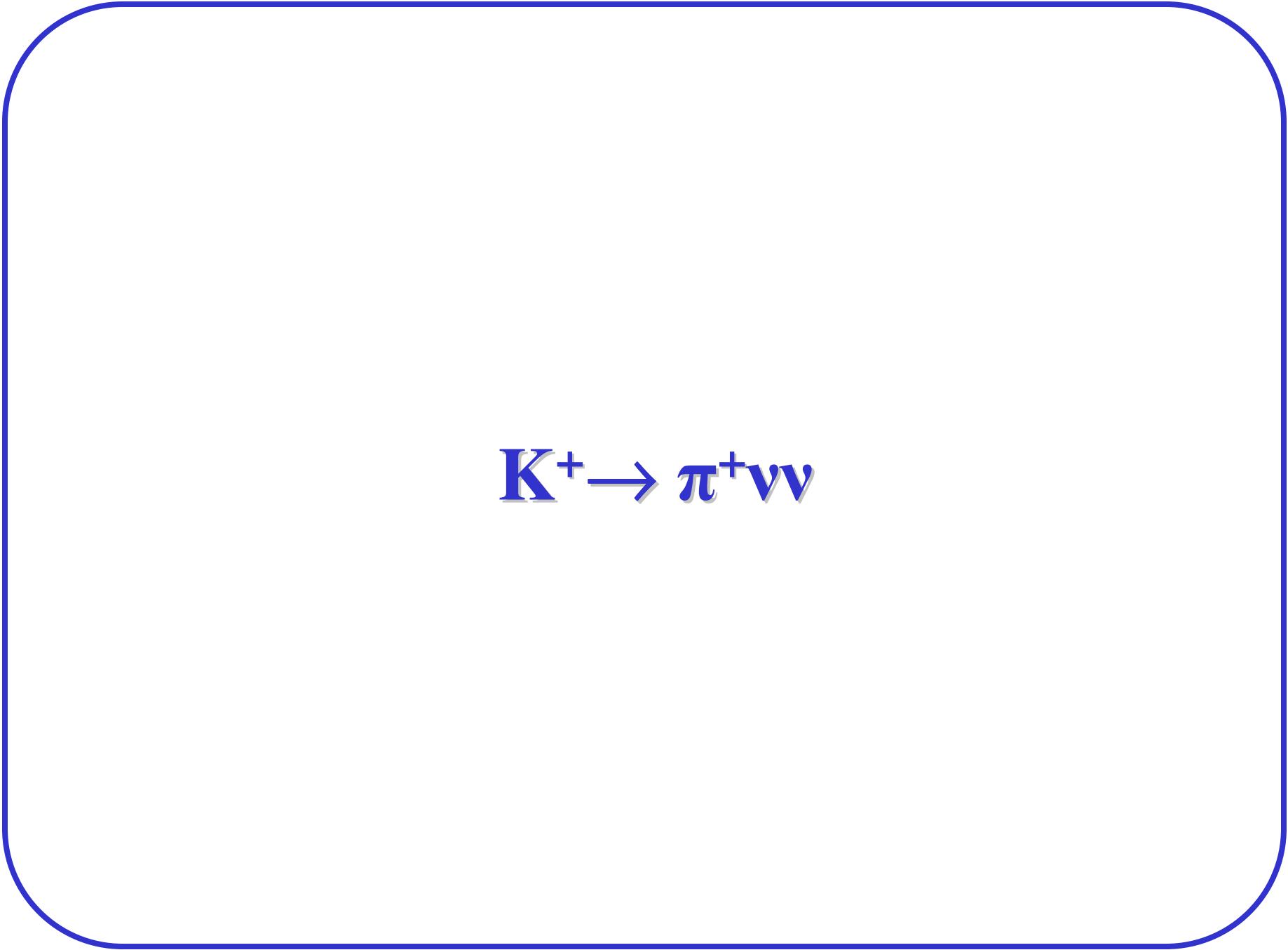
For the E949 collaboration:

Ilektra A. Christidi

SUNY at Stony Brook

April APS meeting 2005

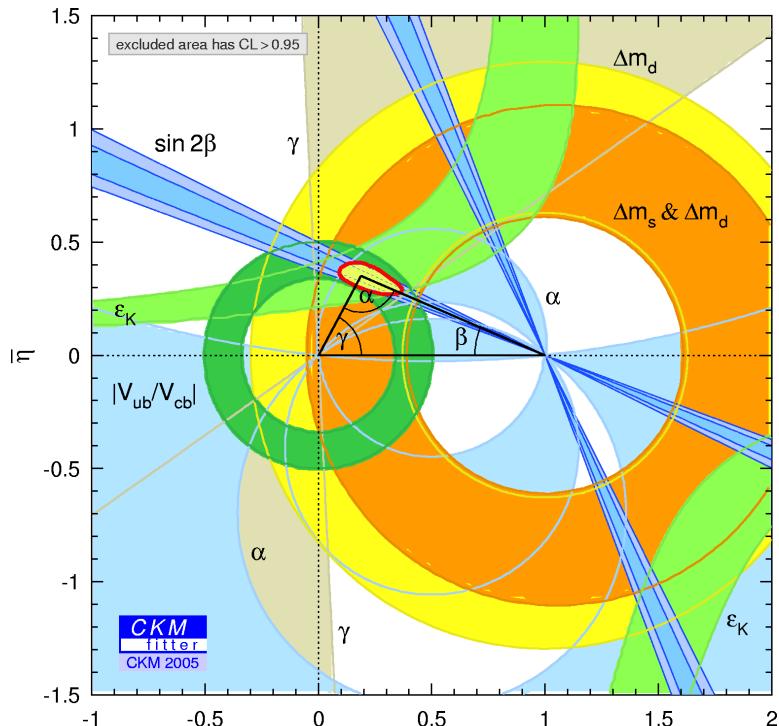
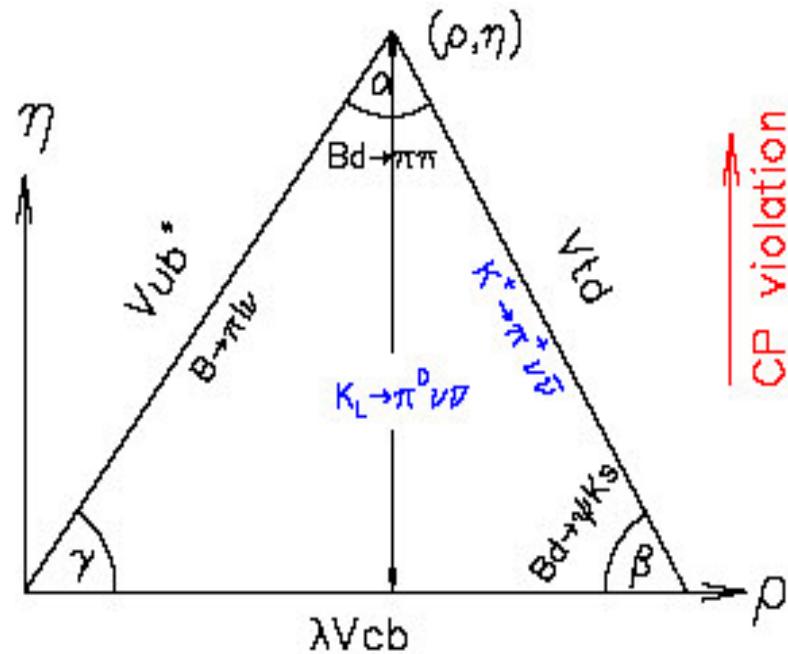
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$$K^+ \rightarrow \pi^+ \nu \bar{\nu}$$

Theory-motivation

Goal: Independently define the Unitarity triangle/ CKM matrix ($A, \lambda, \eta, \rho \rightarrow$ Wolfenstein parameters)

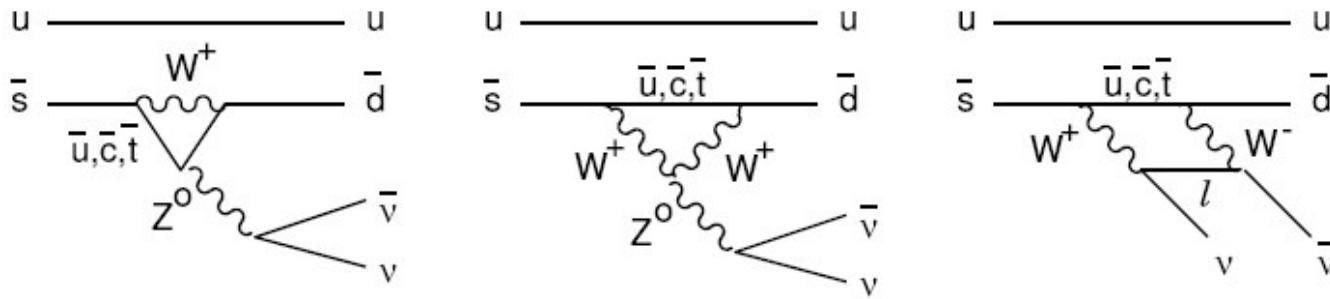
$$V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^* = 0$$



A better determination of V_{td} from $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ will provide a sensitive test of the SM by comparing the results from the K and B sector and probe new physics

The SM $K^+ \rightarrow \pi^+ v\bar{v}$ BR

- Neutral Flavor Changing Process \Rightarrow all diagrams 2nd order
- Main contribution of t in the loop
- Very theoretically “clean” calculation (precision < 5%, uncertainties mainly from c sector)



$$BR(K^+ \rightarrow \pi^+ v\bar{v}) \propto \sum_{l=e,\mu,\tau} \left| V_{cs}^* V_{cd} X(x_c) + V_{ts}^* V_{td} X(x_t) \right|^2 \Rightarrow$$

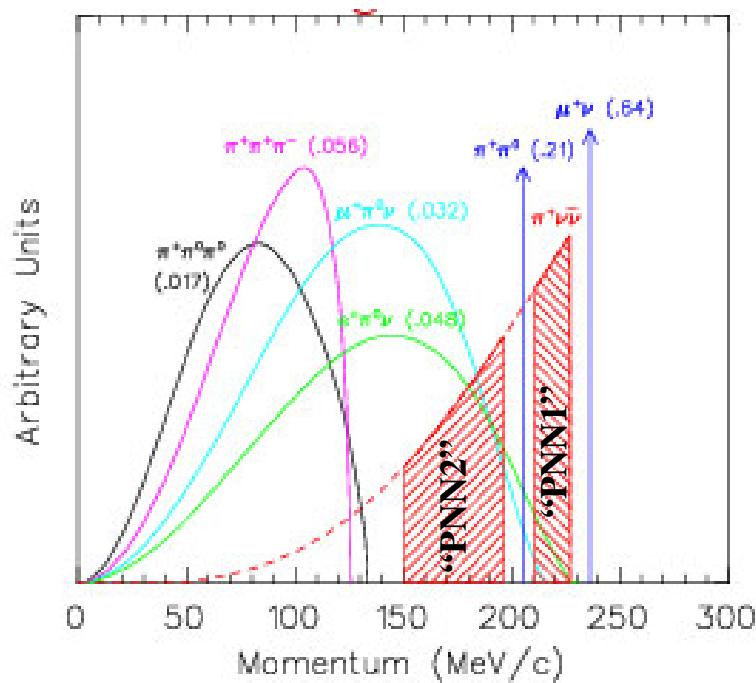
$\dots BR \propto (\sigma \bar{\eta})^2 + (\rho_o - \bar{\rho})^2 \rightarrow \text{ellipse in } \rho\text{-}\eta \text{ plane}$

$$\sigma = \left(\frac{1}{1 - \lambda^2 / 2} \right)^2$$

$$BR_{th}(K^+ \rightarrow \pi^+ v\bar{v}) = (0.77 \pm 0.11) \times 10^{-10}$$

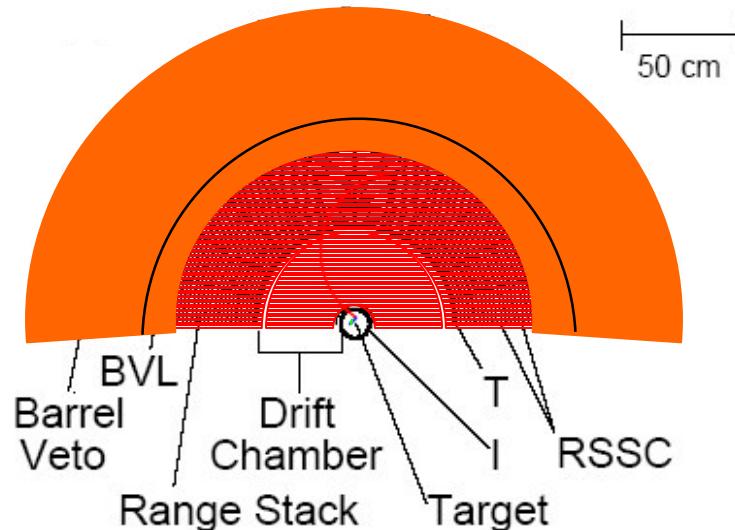
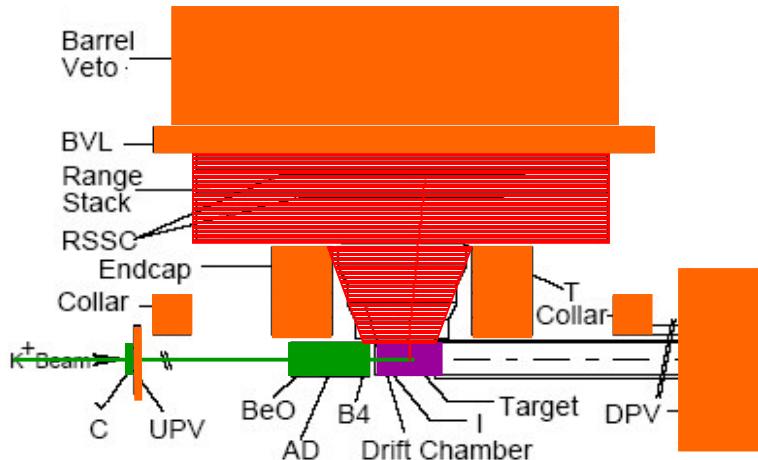
Current situation

| | PNN1 | | PNN2 | |
|---|---|----------------------|---------------------------------|---|
| P_π (MeV/c) | [211,229] | | [140,195] | |
| Years | 1995-98 (E787) | 2002 (E949) | 1996-97 (E787) | 2002 (E949) |
| Stopped K^+ | 5.9×10^{12} | 1.8×10^{12} | 1.7×10^{12} | 1.8×10^{12} |
| Candidates | 2 | 1 | 1 | $S/b = (BR \cdot SES)/b$ ≈ 0.1 |
| Background | 0.15 ± 0.05 | 0.30 ± 0.03 | 1.22 ± 0.24 | GOAL: ~ 1 |
| $BR(K^+ \rightarrow \pi^+ \nu \bar{\nu})$ | $(1.47^{+1.30}_{-0.89}) \times 10^{-10}$ (68% CL) | | $< 22 \times 10^{-10}$ (90% CL) | ? |



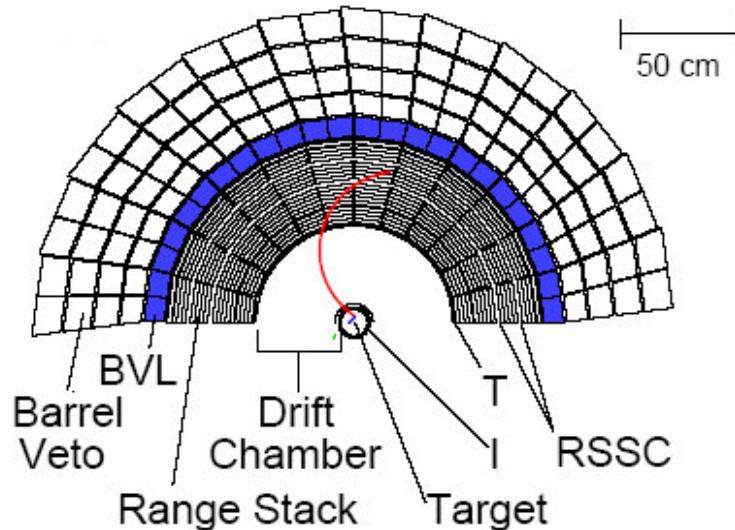
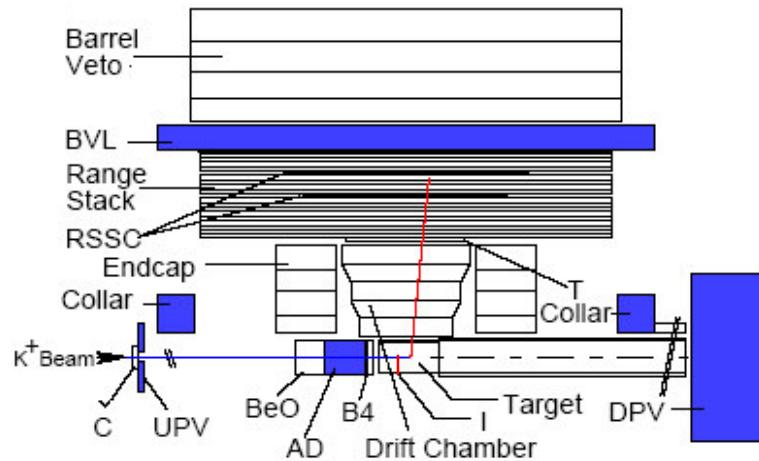
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The measurement w/ E949 detector



- Incoming 700MeV/c beam K slowed down by BeO and AD
- K^+ stops & decays at rest in scintillating fiber target – measure delay (2ns)
- Outgoing π^+ momentum measured in UTC, energy & range in RS and target
- π^+ stops & decays in RS – detect $\pi^+ \rightarrow \mu^+ \rightarrow e^+$ chain
- Photons vetoed hermetically in BV-BVL, RS, EC, CO, USPV, DSPV

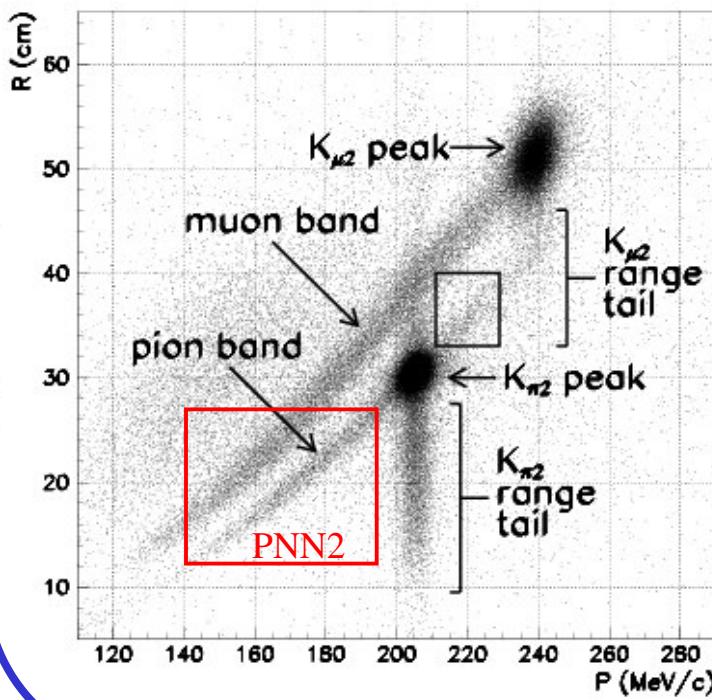
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- Photons vetoed hermetically in BV-BVL, RS, EC, CO, USPV, DSPV
- New/upgraded elements

Backgrounds

- 3-body decay w/ 2 missing particles: $0 \leq p_{\pi^+} \leq 227 \text{ MeV}/c \Rightarrow$
Signal: $\pi^+ + \text{nothing}$, backgrounds (bg) vetoed $\sim 10^{-11}$!
- Need
 - particle identification (PID)
 - all other charged particles vetoed $< 10^{-3}$
 - redundant precise kinematic measurements



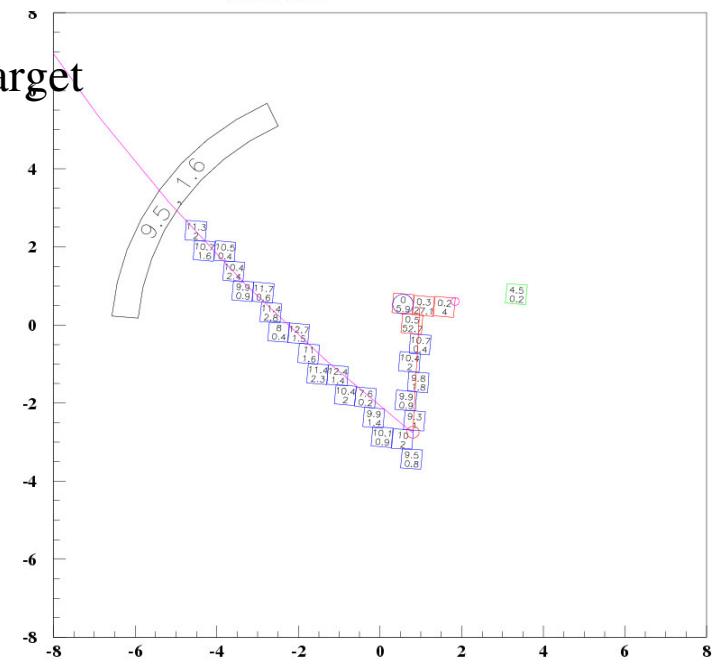
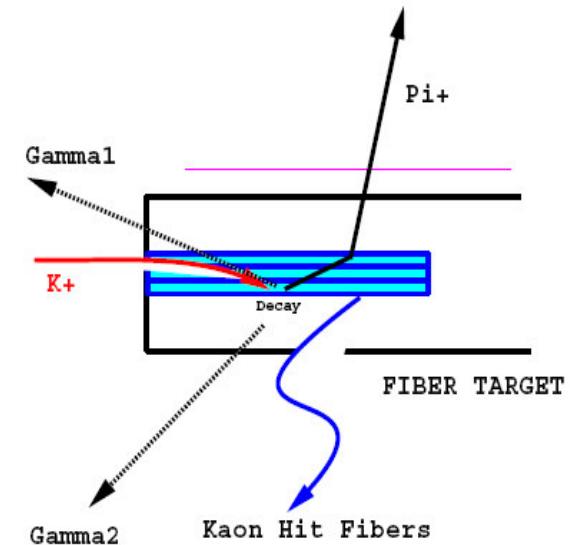
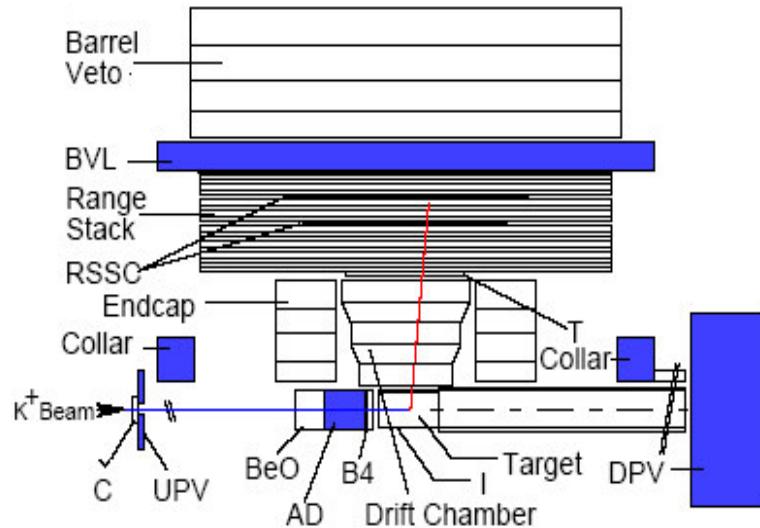
| Background | BR ($\cdot 10^{-3}$) | PID | VETO | KIN. |
|--|-------------------------------|--------------|------------------------|------------------|
| $K^+ \rightarrow \pi^+ \pi^0 (K_{\pi 2})$ | 212 | - | $\checkmark (2\gamma)$ | \checkmark |
| Beam particles | - | \checkmark | $\checkmark (cp)$ | $\checkmark (t)$ |
| $K^+ \rightarrow \pi^+ \pi^- e^+ \nu_e (K_{e4})$ | 0.039 | - | $\checkmark (2cp)$ | - |
| $K^+ \rightarrow \pi^+ \pi^0 \gamma (K_{\pi 2\gamma})$ | 0.275 | - | $\checkmark (3\gamma)$ | - |
| $K^+ \rightarrow \pi^0 \mu^+ \nu_\mu (K_{\mu 3})$ | 31.8 | \checkmark | $\checkmark (2\gamma)$ | - |
| $K^+ \rightarrow \mu^+ \nu_\mu \gamma (K_{\mu\nu\gamma})$ | 5.5 | \checkmark | $\checkmark (1\gamma)$ | - |
| CEX ($K^+ n \rightarrow K^0 p$, $K^0_L \rightarrow \pi^+ \mu^- \nu_\mu$ or $K^0_L \rightarrow \pi^+ e^- \nu_e$) | Prob=0.0015 0.135 0.194 | - | \checkmark | - |

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PNN2 analysis

Main bg mechanism: $K^+ \rightarrow \pi^+\pi^0$ with π^+ scatter in target \Rightarrow

- Simultaneous shift in range AND momentum
- Photons head near beam direction, the weakest PV region of the detector
- *Goal: sensitivity equal to PNN1, s/b = 1 \Rightarrow*
 $2 \times$ acceptance and $5 \times$ rejection
- Improved PV: new detectors at central region (BVL) and small angles
- Improved algorithms to identify π^+ scatters in target



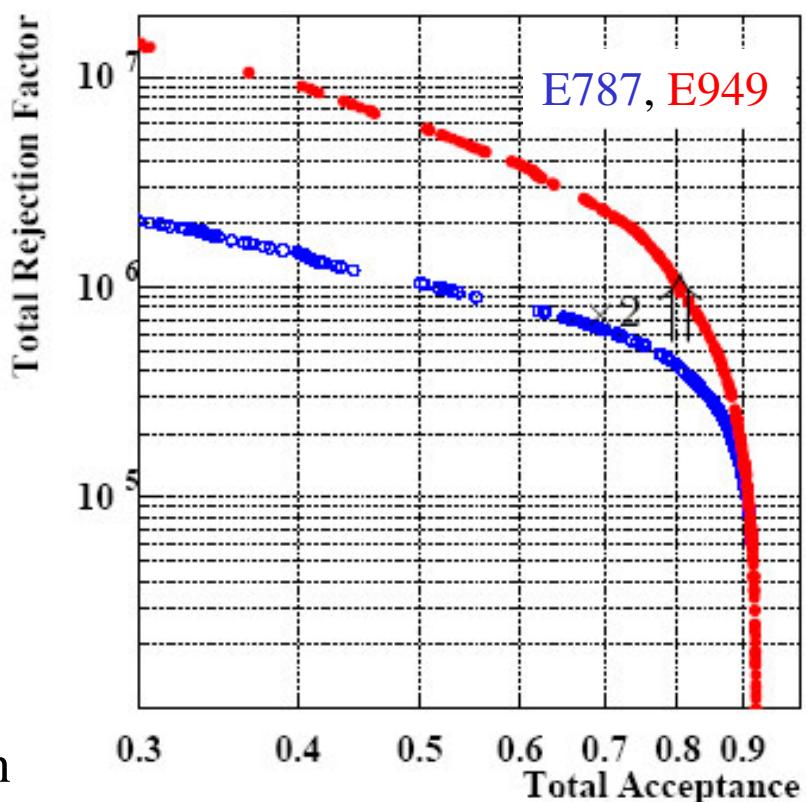
Photon Veto improvement

In the $K_{\pi 2}$ kinematic box:

- ~ *2 × better rejection* at nominal PNN1 acceptance (80%) or
 - ~ *5% more acceptance* with E787 rejection !
- ⇒ Good news for PNN2 as well...

Extra tools for PNN2:

- Active degrader (PV detector near beam)
- Account for “*veto blindness*” (i.e. when an early accidental masks the γ pulse, by using double-pulse information and early-time loose veto.



$$\pi^0 \rightarrow VV$$

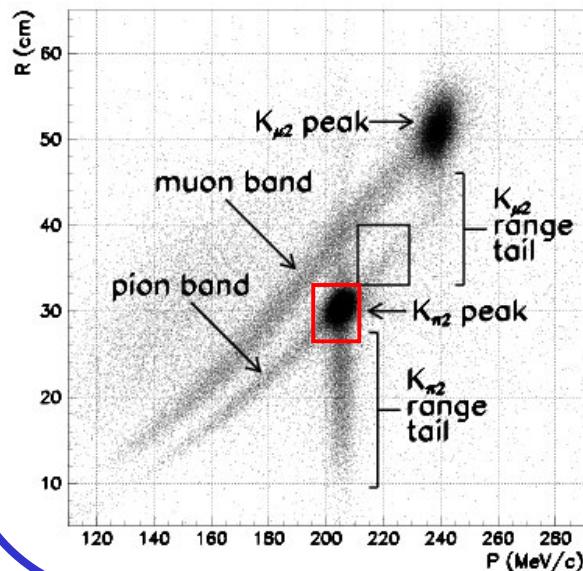
analysis by K.Mizouchi, Kyoto University, Japan

Theoretical motivation

- Decay prohibited by helicity for massless ν
- For massive ν , $BR(\pi^0 \rightarrow \nu\bar{\nu}) = \frac{\Gamma(\pi^0 \rightarrow \nu\bar{\nu})}{\Gamma(\pi^0 \rightarrow \gamma\gamma)} = 1.2 \times 10^{-7} \left(\frac{m_\nu}{m_{\pi^0}} \right)^2 \left(1 - \frac{4m_\nu^2}{m_{\pi^0}^2} \right)^{1/2}$
therefore, for the max $m_{\nu\tau} = 18.2 \text{ MeV}/c$, $BR < 2.1 \times 10^{-9}$
- From cosmology: cooling through the pion pole $\gamma\gamma \rightarrow \pi^0 \rightarrow \nu\nu$ gives $BR < 2.9 \times 10^{-13}$, but it's model dependent
- Existing limits: $BR < 8.3 \times 10^{-7}$ (90% CL) from E787
- Inclusive measurement: $\pi^0 \rightarrow \text{anything invisible} \Rightarrow \text{BSM}$

Background & measurement

- Tag π^0 from $K_{\pi 2}$ ($K^+ \rightarrow \pi^+ \pi^0$) decay $\Rightarrow p_{\pi^0} = p_{\pi^+} = 205 \text{ MeV}/c$
Signal: $\pi^+ + \text{nothing}$, but with fixed 2-body kinematics
- Two steps in selection/bg calculation:
 - $K_{\pi 2}$ tag, non- $K_{\pi 2}$ bg calculated from data w/ blind analysis: 3.07 events
 - Apply tightest PV & look in the box. Conservative limit: all events due to missed photons from detector inefficiencies.



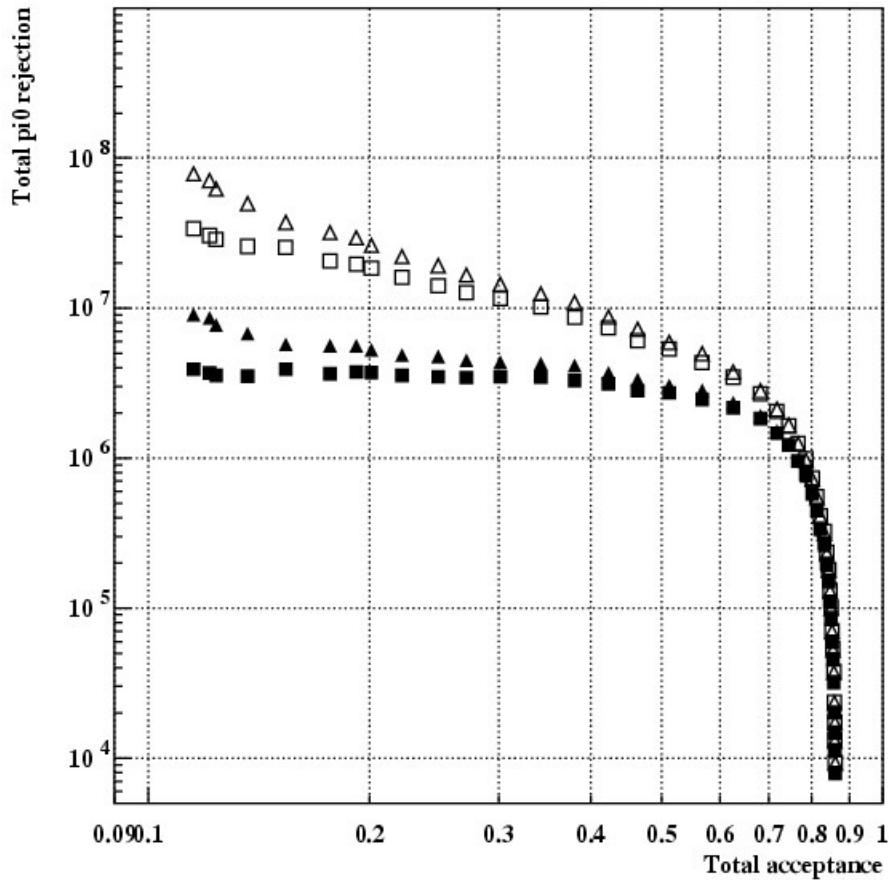
$$BR(\pi^0 \rightarrow \nu \bar{\nu}) < \frac{N_{90}}{N_K BR(K^+ \rightarrow \pi^+ \pi^0) A_{K_{\pi 2}} C_{dis} C_{acc}}$$

Poisson 90% CL
 N_{90}
 # of Kaons
 $A_{K_{\pi 2}}$
 $C_{dis} C_{acc}$
 K_{π2} acceptance
 Correction factors

| Background | BR | Bg |
|--|------|-----------------------|
| $K^+ \rightarrow \mu^+ \nu_\mu (\gamma)$ ($K_{\mu 2(\gamma)}$) | 0.63 | 3.66×10^{-1} |
| Beam particles: | - | |
| Single beam | | 3.27×10^{-2} |
| Double beam | | 2.67 |
| Total | | 3.07 |

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Analysis & result



- PV cuts tuned on 1/3 of the sample, randomly selected, with optimization procedure.
- 1/3 sample discarded, to maintain blindness, and measurement is done with the remaining 2/3.
- Open the 2/3 sample box:
99 events $\Rightarrow 99 - 3.07 = 95.93$ good
 $K_{\pi 2}$ tags $\Rightarrow N_{90} = 110$
- $N_K = 3.019 \times 10^9$
- $A_{K\pi 2} = 0.1173$
- $C_{\text{dis}} \times C_{\text{acc}} = 1.136$

$$\text{So, } BR(\pi^o \rightarrow V\bar{V}) < 2.73 \times 10^{-7}$$

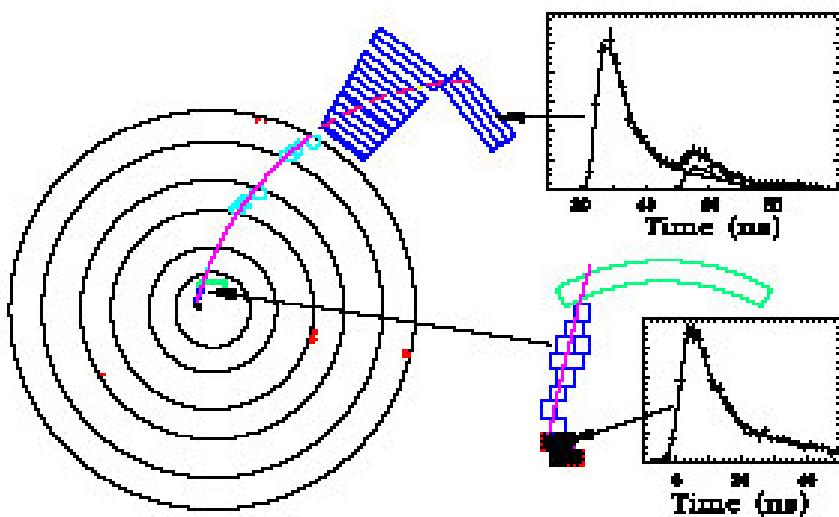
Conclusions

- E787 upgrade into E949 worked as expected: x2 better PV rejection at PNN1 acceptance, x10 at low acceptances
- PNN2 analysis under way, showing signs of improved bg suppression
- Updated $\pi^0 \rightarrow \nu\bar{\nu}$ BR limit, x3 better than before:
 2.73×10^{-7} from 8.3

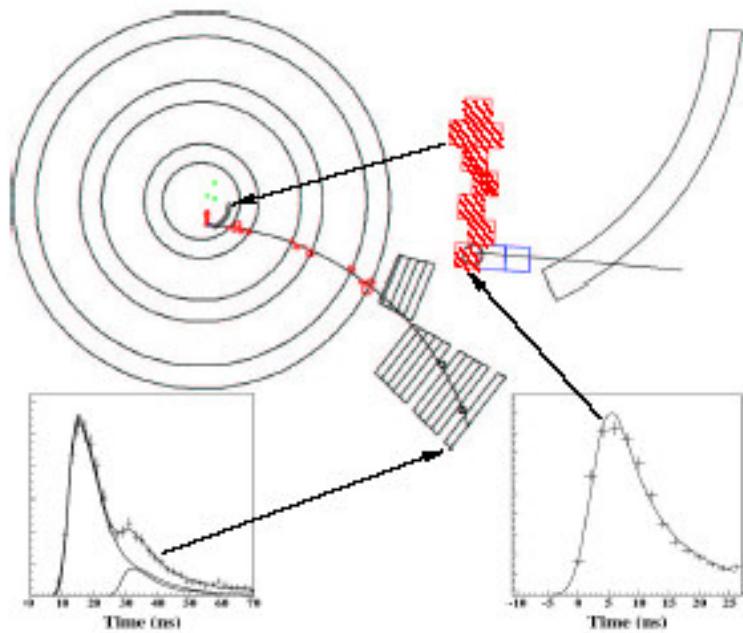
Extras

Previous (E787) results (2)

Candidate E787A



Candidate E787C



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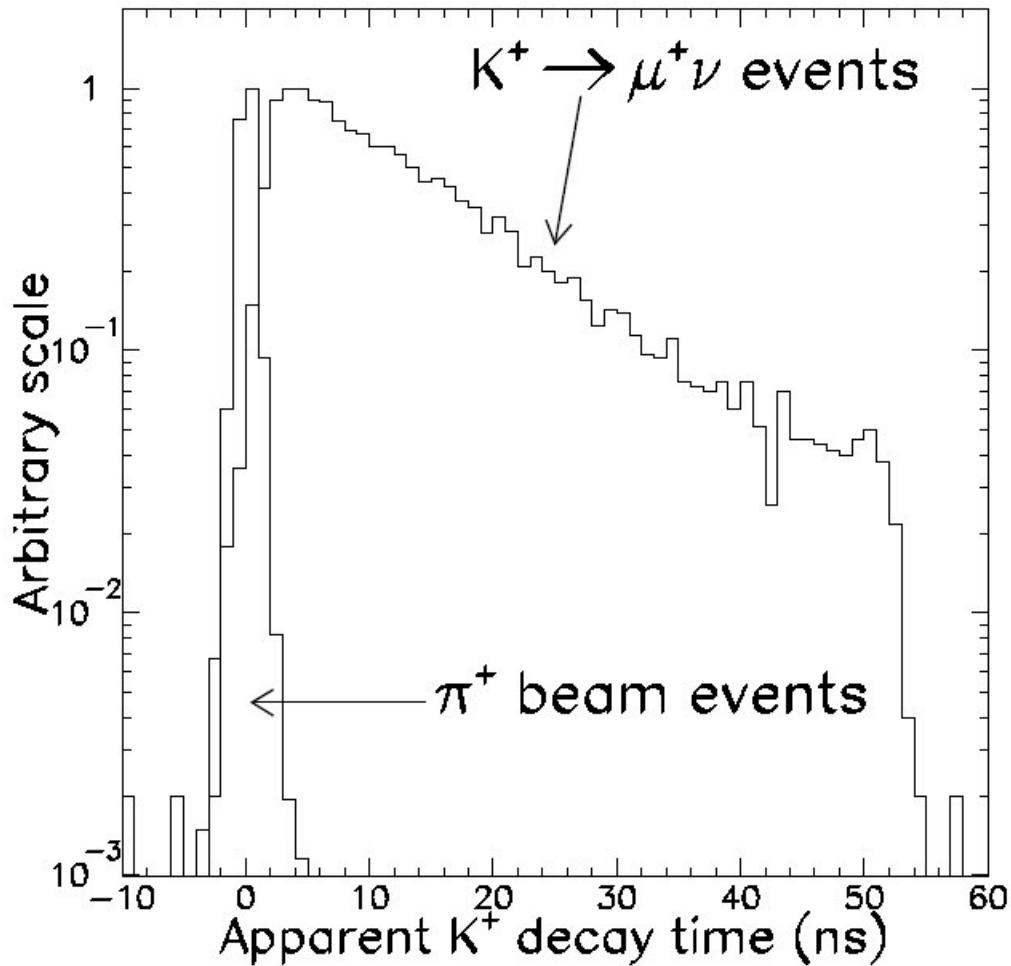
stuff

| | E787 | E949 |
|----------------------------------|-----------------------|-----------------------|
| Stopped K ⁺ (N_K) | 5.9×10^{12} | 1.8×10^{12} |
| Total Acceptance | 0.0020 ± 0.0002 | 0.0022 ± 0.0002 |
| S.E.S. | 0.8×10^{-10} | 2.6×10^{-10} |
| Total Background | 0.14 ± 0.05 | 0.30 ± 0.03 |
| Candidate | E787A | E787C |
| S_i/b_i | 50 | 7 |
| $W_i \equiv \frac{S_i}{S_i+b_i}$ | 0.98 | 0.88 |

| | PNN1 | | PNN2 | |
|--|------------------------------|--------------------------------|------------------------------------|-----------------------|
| P_π (MeV/c) | [211,229] | | [140,195] | |
| Years | 1995-98 (E787) | 2002 (E949) | 1996-97 (E787) | Goals for 2002 (E949) |
| Stopped K ⁺ | 5.9×10^{12} | 1.8×10^{12} | 1.7×10^{12} | 1.8×10^{12} |
| Acceptance | $(2 \pm 0.2) \times 10^{-3}$ | $(2.2 \pm 0.2) \times 10^{-3}$ | $(0.837 \pm 0.003) \times 10^{-3}$ | |
| S.E.S. | 0.8×10^{-10} | 2.6×10^{-10} | 6.9×10^{-10} | |
| Candidates | 2 | 1 | 1 | ? |
| Background | 0.15 ± 0.05 | 0.30 ± 0.03 | 1.22 ± 0.24 | < 1 |
| BR(K ⁺ → π ⁺ νν) | (68% CL) | | $< 22 \times 10^{-10}$ (90% CL) | ? |

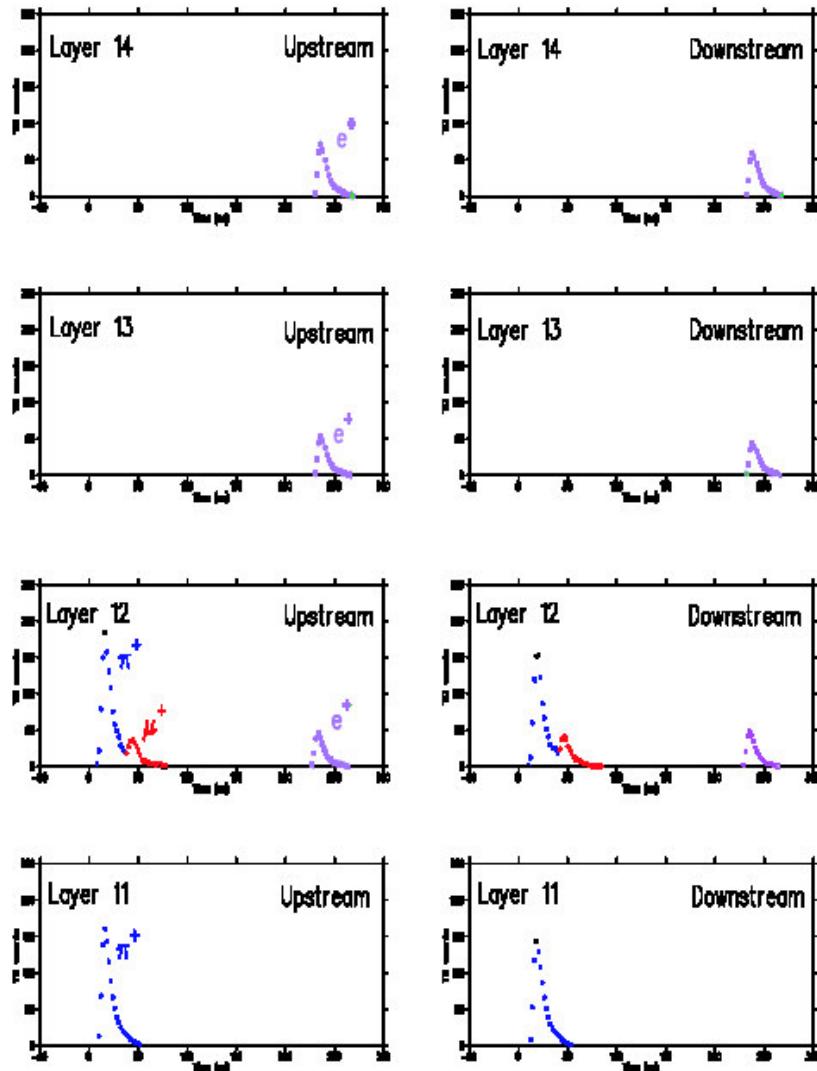
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Delayed coincidence



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$\pi^+ \rightarrow \mu^+ \rightarrow e^+$ identification

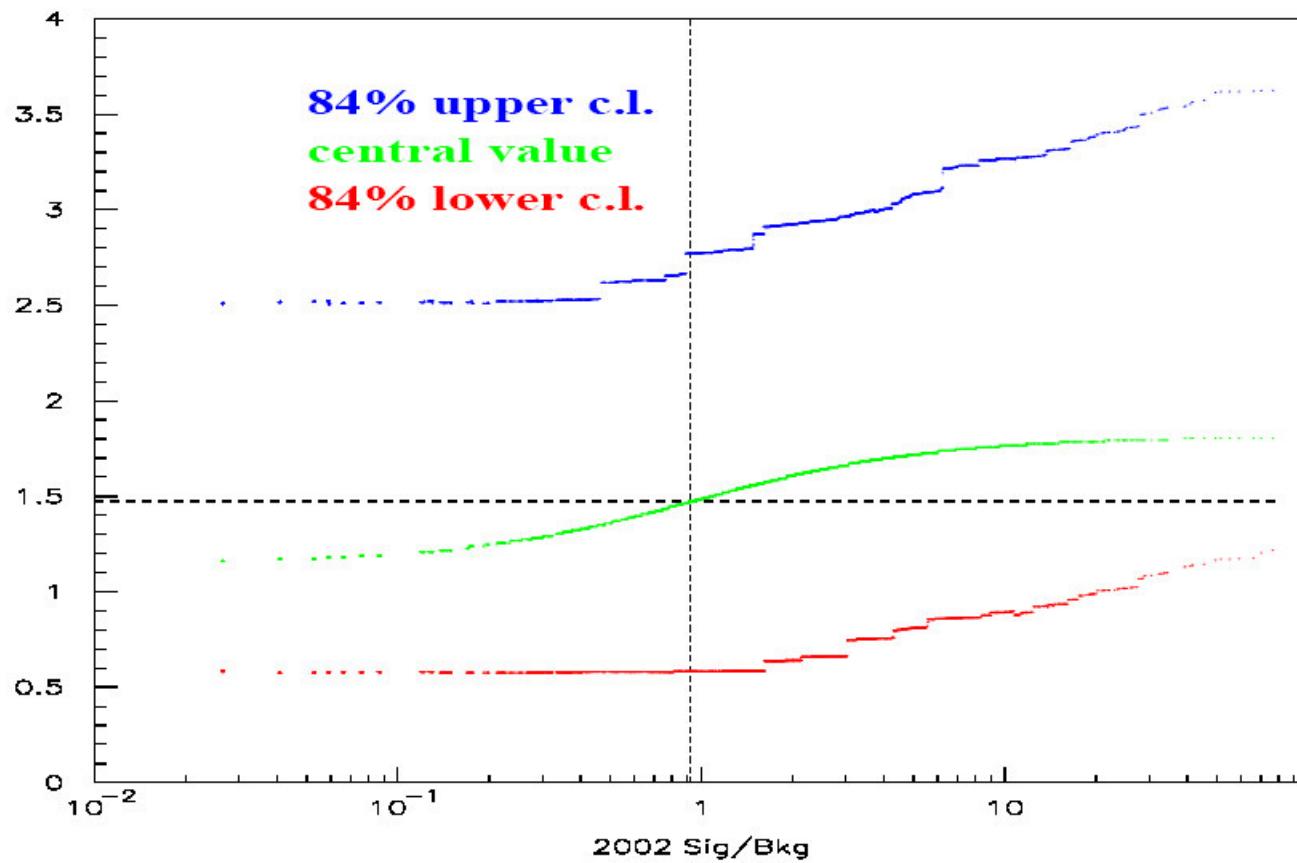


$E_\mu = 4.1 \text{ MeV}$, $R_\mu \sim 1 \text{ mm}$,
 $\tau_\pi = 26 \text{ ns}$

$E_e < 53 \text{ MeV}$, $\tau_\mu = 2.2 \mu\text{s}$

Toy MC for Junk code

BR dependence on s/b of cell where event is found:



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